The value of chest ultrasonography applications in the respiratory ICU

Medhat F. Negm[a], Mohammad H. Kamel[a], Osama I. Mohammad[a], Rehab E. Elsawy[a], Hamada M. Khater[b]

Background Diverse imaging systems can be utilized for the evaluation of chest issues in ICU patients; ultrasound (US) is a decent analytic instrument without exposing the patients to radiation and risk of transfer.

Objectives To compare the diagnostic performance of transthoracic US and bedside chest radiography (CXR) for the detection of various pathological abnormalities in fundamentally sick patients, using chest computed tomography as a gold standard.

Patients and methods Two hundred and fifty-six patients who were admitted in the Respiratory Care Unit were included in this study. CXR, computed tomography, and transthoracic US were done to all the patients. Six pathological entities were evaluated: pleural effusion, pneumothorax, consolidation, interstitial lung diseases, pulmonary embolism, and neoplasms.

Results All patients were evaluated by the three imaging techniques. The sensitivity and specificity of CXR were 42.1, 84.4% for pneumonia 50.0, 90.0% for pleural effusion, 45.5, 90.6% for interstitial syndrome, 50.0, 94.8% for pneumothorax, 60, 100% for pulmonary embolism, and 66, 94% for neoplasm, while the values for chest US were 89.47, 100% for pneumonia, 60, 100% for pulmonary embolism, 100, 100% for pleural effusion, pneumothorax, interstitial syndrome, and neoplasm.

Conclusion US examination of the chest is a noninvasive and promising bedside tool in the evaluation of patients in the Respiratory Care Unit.

Egypt J Bronchol 2019 13:323–327

Egyptian Journal of Bronchology 2019 13:323–327

Keywords: chest ultrasound, pleural effusion, respiratory ICU

Departments of, [a]Chest Diseases, [b]Radiology, Faculty of Medicine, Benha University, Benha, Egypt

Correspondence to Osama I. Mohammad, MD, Faculty of Medicine, Benha, 13511, Egypt. Tel: +20 127 364 6430;
e-mail: osama.thorax@yahoo.com

Received 7 October 2018 **Accepted** 3 December 2018

Introduction

Chest ultrasonography (US) is given more consideration in critical care medicine [1]. The part of transthoracic sonography (TS) in the chest was generally been constrained to the assessment of pleural effusion and as a guide for aspiration. TS has turned into an undeniably profitable demonstrative apparatus in different chest diseases [2]. Its effect on the diagnosis and management has been established in several studies [3,4], particularly under crisis conditions by utilizing TS, a few conditions might be quickly diagnosed (e.g. pneumonia, pulmonary embolism, pleural, and in addition pericardial effusion, pneumothorax, and atelectasis), or even might be suspected (e.g. diffuse parenchymal lung infection) or may act as a guide for the following diagnostic or therapeutic options [e.g. computed tomography (CT), bronchoscopy, or thoracocentesis] [5]. Rather than CT, TS is noninvasive and does not utilize radiation and contrast materials. At long last, portable US permits patient assessment whenever and in wherever [6].

Aim of the work study

To compare the diagnostic performance of transthoracic ultrasound (TUS) and bedside chest radiography (CXR) for the detection of various pathological abnormalities in critically ill patients, using CT as a gold standard.

Patients and methods

This prospective study was performed in the respiratory ICU, Chest Department, Benha University Hospitals from September 2015 to September 2017 and included 256 patients with different respiratory diseases after exclusion of patients with a period of more than 24 h between lung US and radiography or those with radiographic findings known to the physician. Ethical research approval from the Benha University hospitals ethics committee and informed consent from the patient were obtained.

Patients were subjected to:

(1) Full clinical evaluation by history and clinical examination.
(2) Routine laboratory investigation (complete blood count, erythrocyte sedimentation rate, blood sugar, liver and kidney functions).
(3) Bacteriological examination of the sputum was done in 168 patients (either specific in 40 patients or nonspecific in 128 patients).
(4) Echocardiography was done in 48 patients.

 DOI: 10.4103/ejb.ejb_78_18

(5) Doppler US on the lower limb was done in 20 patients, and on the upper limb in four of them.
(6) Abdominal US was done in 20 patients.
(7) Pleural fluid analysis was done in 56 patients with pleural effusion (physical, chemical, bacteriological, and cytological examination).
(8) Conventional radiological methods:
    (a) CXR (was done to all patients).
    (b) CT of the chest (was done to all patients) (high-resolution CT of the chest was done in 44 patients with interstitial lung diseases and CT pulmonary angiography was done in 20 patients with pulmonary embolism).

TUS was performed to all patients included in the study using a portable digital color Doppler US system; model S6, SonoScape (Shanghai, China). Curvilinear probe was used with frequency ranging between 3.5 and 5 MHz. US-guided aspiration was done in 56 patients with pleural effusion diagnosed by TUS and US-guided biopsy was performed in 36 patients with neoplastic lesions diagnosed by TUS.

Interpretation and clinical applications of the sonographic images [7]

(1) US images were displayed on a gray scale. The strongest echo appears white while it appears black when no sound wave is reflected from the organs. Depending on the reflected wave amplitude, the following terms are used to define echogenicity.
    (a) Anechoic: when no sound wave is reflected and the image appears black as in pleural effusion.
    (b) Isoechoic: when the echoes are of comparable amplitude with the surrounding tissue as with the kidneys, liver, or spleen.
    (c) Hyperechoic: when echoes are stronger than the surrounding tissue as in the diaphragm.
    (d) Hypoechoic: when it is weaker than that from the surrounding tissue.
(2) Common sonographic signs that were used to describe the lesions:
    (a) Sliding sign: dynamic transverse twinkling movement visible at the pleural line and synchronized with respiration.
    (b) A lines: horizontal lines parallel to the pleural line recurring at regular intervals (normal sign).
    (c) B lines: vertical pleural-based lines (normal sign if less than three lines per view).
    (d) Consolidation: hypoechoic shadow.
    (e) Pleural effusion: appears mostly as an anechoic, homogeneous space between parietal and visceral pleura.
    (f) Lung point: sudden, on–off visualization of a lung pattern.
    (g) Sinusoids sign: inspiratory centrifugal shifting of the visceral pleura with decrease in apparent thickness of the effusion identified as sinusoidal waveform on M mode and it is specific for pleural effusion.

Ultrasound-guided transthoracic needle biopsy (was done in 36 patients)

(1) The patient is positioned according to the site of lesion to be biopsied – prone for paravertebral lesions and supine for lateral or anterior lesions.
(2) Proper local anesthesia with lidocaine 2% was given.
(3) Biopsies were taken with automatic tru-cut needles 20 cm×18 G.
(4) Three or more core biopsies were obtained to ensure adequate tissue for histopathological diagnosis.
(5) A follow-up CXR was obtained postbiopsy.

Statistical analysis

All data were collected, tabulated, and statistically analyzed using STATA/SE, version 11.2 for Windows (STATA Corporation, College Station, Texas, USA). The collected data were summarized in terms of mean±SD and range for quantitative data and number and percentage for qualitative data. Receiver operating characteristics analysis was carried out to evaluate the diagnostic performance of the different radiological investigations in ICU patients. The sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were estimated and comparisons between CXR and US findings were carried out using the McNemar test (χ^2).

Results

The total number of the studied group was 256 patients, 104 women and 152 men, their age ranged from 16 to 85 years with mean±SD 56.22±14.45. Patients of the study were classified according to their final diagnosis based on CT chest finding as a gold standard for diagnosis into: 76 with pneumonia, 24 with pneumothorax, 56 with pleural effusion of different etiologies, 20 with pulmonary embolism, 44 with interstitial lung diseases, and 36 with neoplasm (Table 1). Of the patients, 14.06% had normal CXR and 85.93% of patients had abnormal finding (23.44% consolidation, 18.76% homogeneous opacity, 15.63% diffuse interstitial pattern, 14.06% mass lesion, 9.37% jet black hyperlucency, and lastly 4.68% wedge-shaped

Table 1 Descriptive analysis of the studied group regarding the final diagnosis

Diagnosis (*N*=256)	*n* (%)
Pneumonia	76 (29.9)
Pneumothorax	24 (9.37)
Pleural effusion	56 (21.87)
Transudate	20/56 (7.86)
Exudate	36/56 (14.06)
Pulmonary embolism	20 (7.83)
Without infarction	8/20 (3.12)
With infarction	12/20 (4.68)
Interstitial lung diseases	44 (17.18)
Neoplasm	36 (14.06)

Table 2 Descriptive analysis of the studied group as regards main chest radiographic findings

Items (*N*=256)	Chest radiographic finding [*n* (%)]
Normal	36 (14.06)
Consolidation	60 (23.44)
Jet black hyperlucency	24 (9.37)
Wedge-shaped opacity	12 (4.68)
Homogenous opacity raising to axilla	48 (18.76)
Mass lesion (neoplasm)	36 (14.06)
Diffuse interstitial pattern	40 (15.63)

Table 3 Descriptive analysis of the studied group regarding main chest ultrasonographic findings

US finding (*N*=256)	*n* (%)
Normal	16 (6.25)
B profile	44 (17.19)
Anechoic lesion	56 (21.87)
Homogeneously echogenic	20/56 (7.81)
Complex nonseptated stuff	24/56 (9.37)
Complex septated	12/56 (4.68)
Hypoechoic pleural thickening	12 (4.68)
Hypoechoic mass lesion	24 (9.38)
M mode (barcode or stratosphere sign), lung point and absent lung sliding	24 (9.38)

US, ultrasonography.

Table 4 Descriptive analysis of the studied group regarding ultrasonographic-guided procedures

Procedures	*n* (%)
Guided biopsy (*N*=36)	
Mesothelioma	12 (33.33)
Adenocarcinoma	12 (33.33)
Lymphoma	8 (22.22)
Metastatic breast cancer	4 (11.11)
Guided aspiration (*N*=56)	
Free anechoic effusion	20 (35.71)
Complex nonseptated	24 (42.86)
Complex septated	12 (21.43)

Table 5 Diagnostic performance of chest radiography regarding the final diagnosis

Diagnosis (*N*=256)	Prevalence (%)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Pneumonia	30.0	42.1	84.4	53.3	77.6
Pneumothorax	9.4	50.0	94.8	50.0	94.8
Pleural effusion	22.0	50.0	90.0	58.3	86.5
Pulmonary embolism	7.8	60.0	100.0	100.0	96.7
Interstitial lung diseases	17.0	45.5	90.6	50.0	88.9
Neoplasm	14.0	66.7	94.5	66.7	94.5

NPV, negative predictive value; PPV, positive predictive value.

peripheral opacity) (Table 2). However, only 6.25% of the patients had normal chest US study and 93.75% of the patients had abnormal chest US [anechoic lesion 21.87%, B profile 17.19%, hypoechoic mass lesion 9.38%, and M mode (barcode or stratosphere sign), lung point, and absent lung sliding 9.38%, and lastly hypoechoic pleural thickening 4.68%] (Table 3). In this study, 92 (35.9%) patients had undergone US-guided procedures, 36 (39%) of them had undergone US-guided biopsy, and 56 (61%) of them had undergone US-guided aspiration of the pleural fluid (Table 4). In the present study, prevalence, sensitivity, specificity, PPV, and NPV of CXR among patients were: pneumonia 30, 42.1, 84.4, 53.3, and 77.6%, respectively, pleural effusion 22, 50, 90, 58.3, and 86.5%, respectively, pneumothorax 9.4, 50, 94.8, 50, and 94.8%, respectively, interstitial lung diseases 17, 45.5, 90.6, 50, and 88.9%, respectively, pulmonary embolism 7.8, 60, 100, 100, and 88.9%, respectively, and neoplasm 14, 66.7, 94.5, 66.7, and 94.5%, respectively (Table 5). In the current study, prevalence, sensitivity, specificity, PPV, and NPV of chest US among patients were: pneumonia 30, 89.47, 100, 100, and 95.7%, respectively, pleural effusion 22, 100, 100, 100, and 100%, respectively, pneumothorax 9.4, 100, 100, 100, and 100%, respectively, interstitial lung diseases 17, 100, 100, 100, and 100%, respectively, pulmonary embolism 7.8, 60, 100, 100, and 96.7%, respectively, and neoplasm 14, 100, 100, 100, and 100%, respectively (Table 6). In our study by comparing the overall accuracy of TUS findings in relation to CXR, it was found that TUS sensitivity, specificity, PPV, NPV were significantly higher than that of CXR (94.4, 100, 100, and 93.3% for TUS vs. 52.8, 57.1, 61.3, and 48.5% for CXR; $P<0.001$) in the diagnosis of parenchymal lung diseases, and it was 100, 100, 100, and 100% for TUS versus 56.5, 80.5, 61.9, and 76.7% for CXR; $P<0.001$) in pleural diseases and it was the same in vascular lung diseases (Table 7).

Table 6 Diagnostic performance of ultrasonography regarding the final diagnosis

Diagnosis (*N*=256)	Prevalence (%)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Pneumonia	30.0	89.47	100.0	100.0	95.7
Pneumothorax	9.4	100.0	100.0	100.0	100.0
Pleural effusion	21.8	100.0	100.0	100.0	100.0
Pulmonary embolism (infarction)	7.8	60.0	100.0	100.0	96.7
Interstitial lung diseases	17.0	100.0	100.0	100.0	100.0
Neoplasm	14.0	100.0	100.0	100.0	100.0

NPV, negative predictive value; PPV, positive predictive value.

Table 7 Statistical comparison between chest radiography and chest ultrasonography as a diagnostic tool in parenchymal, pleural, and vascular lung diseases

N=256	Parenchymal		Pleural		Vascular	
	CXR	US	CXR	US	CXR	US
Prevalence (%)	56.0		36.0		7.8	
Sensitivity (%)	52.8	94.4	56.5	100	60.0	60.0
Specificity (%)	57.1	100	80.5	100	100.0	100.0
PPV (%)	61.3	100	61.9	100	100.0	100.0
NPV (%)	48.5	93.3	76.7	100	96.7	96.7
P	<0.001 (HS)		<0.001 (HS)		–	

CXR, chest radiography; HS, highly significant; NPV, negative predictive value; PPV, positive predictive value; US, ultrasound.

Discussion

Imaging assumes a critical part in conjunction with clinical information in the evaluation and management of patients in the Respiratory Care Unit [8]. To date, radiography and CT are the imaging modalities utilized for detection and follow up of thoracic diseases together with portable US machines which is accessible, bedside, safe, and cheaper [9]. In our study, the prevalence, sensitivity, specificity, PPV, and NPV of CXR in cases of pneumonia were 30, 42.1, 84.4, 53.3, and 77.6%, respectively. The corresponding values for TUS were 30, 89.47, 100, 100, and 95.7%, respectively. Agmy *et al.* [10] found that the sensitivity and specificity of CXR were 40 and 85% for consolidation and the corresponding values for TUS were 87 and 100%. These results were also in agreement with the study of Cortellaro *et al.* [11] who found that the sensitivity and specificity of TUS were 98 and 95% for pneumonia, the feasibility of US was 100%, and the procedure was always done in less than 5 min. On the other hand Nafae *et al.* [12] found that the sensitivity and specificity of CXR were 77.5 and 60% and the corresponding values for TUS were 75 and 97% for pneumonia. In this study, the sensitivity and specificity of CXR in the diagnosis of pleural effusion were 22, 50, 90, 58.3, and 86.5%, respectively and the corresponding values for TUS were 22, 100, 100, 100, and 100%, respectively. These results agreed with Remerand *et al.* [13] who found that the sensitivity and specificity of CXR in the diagnosis of pleural effusion were 65, and 81%, respectively, and the corresponding values for TUS were 100 and 100%. In the present study the prevalence, sensitivity, specificity, PPV, and NPV of CXR in cases of pneumothorax were 9.4, 50, 94.8, 50, and 94.8%, respectively and the corresponding TUS has been successfully used for the identification of pneumothorax in all patients with sensitivity and specificity of 100 and 100%, respectively. Hyacinthe *et al.* [14] found that the sensitivity and specificity of CXR were 75, and 98% for the diagnosis of pneumothorax and the corresponding values for TUS were 98 and 100%, respectively. Interstitial syndrome is of prime importance for diagnosing acute respiratory failure and acute circulatory failure. In our study, the prevalence, sensitivity, specificity, PPV, and NPV of CXR in cases of interstitial lung diseases were 17, 45.5, 90.6, 50, and 88.9%, respectively and the corresponding TUS values were 17, 100, 100, 100, and 100%, respectively, making chest US much more sensitive and specific than bedside CXR in identifying interstitial syndrome. These results were closer to Galbois *et al.* [15] who found that sensitivity and specificity of CXR were 46, and 80% and the corresponding values for TUS were 94, and 93% for interstitial syndrome, respectively. In the current study, the prevalence, sensitivity, specificity, PPV, and NPV of CXR in cases of pulmonary embolism were 7.8, 60, 100, 100, and 88.9%, respectively and the corresponding TUS were 7.8, 60, 100, 100, and 96.7%, respectively. Pulmonary infarcts were diagnosed in 12 (4.68%) patients from 20 (7.81%) cases with pulmonary embolism diagnosed with CT pulmonary angiography; so normal chest US dose not rule out pulmonary embolism. This results were closer to Suzan *et al.* [16] who found that sensitivity and specificity of TUS of 71.9% and 80.9% for pulmonary embolism. However, these results disagreed with Lechleitner *et al.* [17] who found that sensitivity and specificity of TUS were 86% and 67% for pulmonary embolism. The main problem in many prospective studies which dealt with the accuracy of chest sonography in the diagnosis of pulmonary embolism, is the virtual absence of a gold standard signs. In our study, the prevalence, sensitivity, specificity, PPV, and NPV of CXR in cases of neoplasm were 14, 66.7, 94.5, 66.7, and 94.5%, respectively and the corresponding TUS were 14, 100, 100, 100, and 100%, respectively. These results agreed with Wernecke and Diederich [18]

who found that the sensitivity and specificity of TUS in the assessment of lung and mediastinal masses were 99 and 100%. But in the paravertebral compartment CT was the gold standard. The current study also agreed with Diacon *et al.* [19] who reported that chest US guidance improves the appropriateness of needle insertion site selection and also reported 86% sensitivity and 100% specificity with TUS-guided biopsy. In the present study by comparing the overall accuracy of TUS findings in relation to CXR, it was found that TUS accuracy was significantly higher than that of CXR (94.4 vs. 52.8%; $P<0.001$) in the diagnosis of parenchymal lung diseases, and it was 100 versus 56.5% ($P<0.001$) in pleural diseases. Indeed, bedside TUS has been shown to have superior accuracy when evaluating patients with pneumonia, pneumothorax, pleural effusion, neoplasm, or interstitial syndrome, compared with CXR. Also, Koenig *et al.* [20] found that the US was significantly more accurate than CXR in the diagnosis of chest diseases (83 vs. 63%, respectively; $P<0.02$). Brook *et al.* [21] also found that in a general ICU population lung US has a considerably better diagnostic performance than bedside CXR for the diagnosis of most common pathologies.

Conclusion

US examination of the chest is a noninvasive and promising bedside tool for the examination of Respiratory Care Unit patients. TUS has a better diagnostic performance than CXR for the diagnosis of most common respiratory pathologies.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1 Havelock T, Teoh R, Laws D, Gleeson F. Pleural procedures and thoracic ultrasound: British Thoracic Society pleural disease guideline. *Thorax* 2010; **65**(Suppl 2):ii61–ii76.

2 Copetti R, Cattarossi L. The 'double lung point': an ultrasound sign diagnostic of transient tachypnea of the newborn. *Neonatalogy* 2007; **91**:203–209.

3 Khalil MM, ELMaraghy AA, Yousef YR. Could chest ultrasonography replace routine chest X-rays in mechanically ventilated patients? *Egypt J Chest Dis Tuberc* 2015; **64**:857–863.

4 Salah H. Diagnostic impact of integrating ultrasonography into routine practice in respiratory intensive care units. *Egypt J Bronchol* 2014; **8**:66.

5 Sartori S, Tombesi P, Trevisani L. Accuracy of transthoracic sonography in detection of pneumothorax after sonographically guided lung biopsy. *Am J Roentenol* 2007; **188**:37–41.

6 Zhang M, Liu ZH, Yang JX, Jian-Xin G, Shao-Wen X, Guan-Yu J, *et al.* Rapid detection of pneumothorax by ultrasonography in patients with multiple traumas. *Crit Care* 2006; **10**:R112.

7 Islam S, Tonn H, Bolliger CT, Herth FJF, Mayo PH, Miyazawa T, Beamis JF. (eds). *Clinical chest ultrasound: from the ICU to the bronchoscopy suite. Prog Respir Res* Basel, Karger 2009; **37**:11–20.

8 Adhikari S, Amini R, Stolz L. Impact of point-of-care ultrasound on quality of care in clinical. *Practice Rep Med Imag* 2014; **7**:81–93.

9 Saraogi A. Lung ultrasound: present and future lung. *India* 2015; **32**:250–257.

10 Agmy GM, Mohamed S, Gad Y. Transthoracic chest ultrasound in critically ill patients: comparison with bedside chest radiography. *Eur Respir J* 2014; **44**:P4968.

11 Cortellaro F, Colombo S, Coen D, Duca PG. Lung ultrasound is an accurate diagnostic tool for the diagnosis of pneumonia in the emergency department. *Emerg Med J* 2012; **29**:19–23.

12 Nafae R, Shebl ER, El-Ghamry R, Nagat AM, Ragheb AS. Adjuvant role of lung ultrasound in the diagnosis of pneumonia in intensive care unit patients. *Egypt J Chest Dis Tuberc* 2013; **62**:281–285.

13 Remerand F, Dellamonica J, Mao Z, Ferrari F, Bouhemad B, Jianxin Y, *et al.* Multiplane ultrasound approach to quantify pleural effusion at the bedside. *Intensive Care Med* 2010; **36**:656–664.

14 Hyacinthe AC, Broux C, Francony G, Bouzat P, Ferretti GR, Payen J-F, *et al.* Diagnostic accuracy of ultrasonography in the acute assessment of common thoracic lesions after trauma. *Chest* 2012; **141**:1177–1183.

15 Galbois A, Ait-Oufella H, Baudel JL, Maury E. Pleural ultrasound compared to chest radiographic detection of pneumothorax resolution after drainage. *Chest* 2010; **138**:648–655.

16 Suzan S, Agmy GM, Ahmed K, FaragSaid A. Diagnostic performance of trans-thoracic sonography in patients of pneumonia and pulmonary embolism. *Egypt J Chest Dis Tuberc* 2016; **65**:621–628.

17 Lechleitner P, Raneburger W, Gamper G, Riedl B. Lung sonographic findings in patients with suspected pulmonary embolism. *Ultraschall Med* 1998; **19**:78–82.

18 Wernecke K, Diederich S. Sonographic features of mediastinal tumors. *Am J Radiol* 1994; **181**:1357–1364.

19 Diacon A, Theron J, Schubert P, Schuurmans MM, Theron J, Schubert PT, *et al.* Ultrasound-assisted transthoracic biopsy: fine-needle aspiration or cutting-needle biopsy? *Eur Respir J* 2007; **29**:357–362.

20 Koenig SJ, Narasimhan M, Mayo PH. Thoracic ultrasonography for the pulmonary specialist. *Chest* 2011; **140**:1332–1341.

21 Brook OR, Beck-Razi N, Abadi S, Filatov J. Sonographic detection of pneumothorax by radiology residents as part of extended focused assessment with sonography for trauma. *J Ultrasound Med* 2009; **28**:749–755.